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VALIDATION OF A SIMPLE METHOD FOR MONITORING AERIAL ACTIVITY OF SPIDERS

Pernille Thorbek[1]: Department of Landscape Ecology, National Environmental Research Institute, Kalø, DK-8410 Rønde, Denmark and Department of Zoology, University of Aarhus, DK-8000 Aarhus C, Denmark. E-mail: per@dmu.dk

Chris J. Topping: Department of Landscape Ecology, National Environmental Research Institute, Kalø, DK-8410 Rønde, Denmark

Keith D. Sunderland: Horticulture Research International, Wellesbourne, Warwickshire, CV35 9EF, UK

ABSTRACT. Many species of spider disperse by ballooning (aerial dispersal), and indices of aerial activity are required in studies of population dynamics and biological control in field crops where spider immigrants are needed for pest suppression. Current methods (e.g., suction traps, sticky traps, deposition traps) of monitoring aerial activity are very labor-intensive, expensive, or require a power supply. We tested Ballooning Index (BI), an alternative, simple method utilizing inexpensive equipment. This method involved the monitoring of spiders climbing an array of 30 cm tall wooden sticks placed vertically in short turf. During a two-year study in arable land in the UK, the incidence of spiders (mainly Linyphiidae) on sticks was correlated with the numbers caught at 1.4 m and 12.2 m above ground in suction traps. Climbing activity on sticks was greater during the morning than in the afternoon, and this activity started progressively earlier in summer than in winter. There was no seasonal change in the proportion of spiders caught at the two heights in suction traps. The pattern of catches (on sticks and in suction traps) suggested strongly that the majority of ballooning spiders dispersed by a number of short flights, rather than by a single long flight, and that segregation of immigrants and emigrants is not possible by any current method. The BI method appears to be, however, a simple and reliable technique for monitoring the overall aerial activity of ballooning spiders.

Keywords: Aerial dispersal, ballooning height, seasonal variation, Linyphiidae, Araneae

Spiders are generalist predators that may be of great importance in reducing, and even preventing, outbreaks of insect pests in agriculture (Riechert & Lockley 1984; Sunderland et al. 1986). Hence it might be profitable to create and sustain high densities of spiders in fields. However, agricultural cultivations kill spiders and destroy their habitats (Thomas & Jepson 1997; Topping & Sunderland 1998). Furthermore, fields vary in their suitability as habitats for spiders over the growing season of the crop (Dinter 1996). Therefore the ability to disperse well is vital for the persistence and survival of spiders in agricultural habitats (Weyman 1993 and references therein). Recolonization of the fields is normally by aerial dispersal rather than by cursorial movements (Bishop & Riechert 1990), but this varies among species (Thomas et al. 1990). Several studies have suggested that spider dispersal and re-colonization of fields are significant aspects of spider population dynamics in agroecosystems (Bishop & Riechert 1990; Nyffeler & Breene 1990; Dinter 1996; Thomas & Jepson 1997; Topping & Sunderland 1998; Thomas et al. 1990). Therefore, to understand the population and spatial dynamics of spiders in arable land, it is necessary to study their dispersal.

Aerial dispersal of spiders has proven laborious and expensive to measure (Topping & Sunderland 1995). Various methods have been used to monitor aerial activity by spiders, e.g., by suction traps at 12.2 m (Toft 1995; Blandenier & Fürst 1998) and 1.4 m (Topping & Sunderland 1995) above ground, rotary trap (Topping et al. 1992; Topping & Sunderland 1995), deposition traps (Topping & Sunder-

[1] Corresponding author.

land 1995; Weyman et al. 1995), sticky traps (e.g., Greenstone et al. 1985; Plagens 1986), and aircraft-mounted trapping devices (Greenstone 1991). They all give good measures of aerial activity, but are not always practical, especially when finances and time are limited. Suction traps require a power supply and are expensive, aircraft-mounted equipment is expensive to use and sticky trap and deposition trap samples (water trays) take a long time to process (Topping & Sunderland 1995).

Here a simple method, utilizing inexpensive equipment, for measuring aerial dispersal of spiders is proposed, i.e., monitoring the number of spiders that climb up wooden sticks placed vertically in closely-mown grass turf (hereafter termed the "Ballooning Index" or BI method). BI is a simple method, which does not require a power supply or much time to process. This is not an entirely new approach; similar methods were used in pioneering studies on spider dispersal (Duffey 1956; van Wingerden & Vugts 1974; Vugts & van Wingerden 1976). Furthermore, Weyman (1995) has shown, under laboratory conditions, that climbing a vertical structure is a part of pre-ballooning behavior, but to our knowledge no one has determined whether attempts at ballooning by spiders on the ground correspond to the aerial density of ballooning spiders. Here we describe our test of whether pre-ballooning behavior on the ground (BI) corresponded well with aerial density as measured by suction traps (at 1.4 m and 12.2 m).

There is likely to be a positive correlation between height of ballooning and distance travelled per flight (Thomas 1992). The latter is of great significance in relation to annual re-colonization of fields from reservoir habitats (Sunderland & Samu 2000). Danish data (Toft 1995) suggest that the majority of spiders balloon closer to the ground during the colder seasons than in summer. If this is true, there will be fewer long-distance migrants (as assessed by the 12.2. m trap) during winter. Hence, BI (being close to the ground) would tend to overestimate the aerial dispersal of spiders, as the spiders would climb the sticks to take off, but would not go very far. Therefore, we tested whether there was a difference in the height at which spiders ballooned at different times of year, to determine whether the findings for Denmark (Toft 1995) also apply in the UK.

METHODS

Study area.—The study was carried out in West Sussex, UK (at grid reference 04TQ 045 035) at the edge (just outside the crop) of a 3 ha winter wheat (cv. Riband) field. The field received normal agrochemical applications but no insecticides were required during the experiment. Adjacent to the field there was a conurbation to the south, east and west and arable land to the north.

Dispersal.—Three methods were used to measure the dispersal activity of spiders: a suction trap at 1.4 m above ground, a suction trap at 12.2 m above ground and BI.

Suction traps: The 1.4 m suction trap (46 cm Enclosed Cone Propeller Suction Trap (Taylor 1955)) sampled air at a rate of 70–75 m^3 min^{-1}. The 12.2 m suction trap (Rothamsted Insect Survey Trap) sampled air at a rate of 45–50 m^3 min^{-1} (Macaulay et al. 1988). To standardize the catch from the two suction traps, the catch from the 1.4 m suction trap was multiplied by 0.67 to standardize to 50 m^3 min^2.

The 1.4 m and the 12.2 m suction traps were placed 5 m apart on grass just outside the field's southern edge. The suction traps were operated for two years, from April 1990 to December 1991. In 1990 the trap samples were segregated into night and day samples. In 1991 both suction traps sampled 24 h/day and were emptied daily between 0730–1030 h. Each suction sample took on average 10–20 min to process.

BI: The incidence of spiders preparing to balloon was assessed by observing spiders climbing wooden sticks. Twenty cylindrical sticks (40 cm long, 0.5 cm diameter) were set vertically into a lawn (with 30 cm being above ground) in a 5 X 4 grid, each row and column being 60 cm apart. The lawn, which was mown approximately weekly, was sited on the western edge of the winter wheat field at 60 m from the suction traps.

It was assumed that spiders climbed the sticks as part of pre-ballooning behavior. However, as this might not be the case, it was also noted when spiders actually attempted to take off, i.e., showed "tip-toe" behavior. Tip-toe behavior (a stereotyped posture, whereby spiders raise their bodies above the substrate to bring themselves into more rapidly moving air (Richter 1970; Suter 1991)) is a well-known component of pre-ballooning behavior. The time of day, wind speed and number of spiders climbing the sticks, and whether they showed tip-toe behavior were noted for each observation. The wind speed was measured 1 m above ground by an anemometer attached to a Squirrel® datalogger (Grant Instruments, Cambridge, UK). After each observation (which took approximately 5 min for the 20-stick array), spiders on the sticks were gently brushed off the sticks and onto the grass below. The BI method therefore does not preclude the possibility that some individual spiders are recorded in more than one observation period.

BI was carried out from 24 April–28 November 1991. BI was done only during the daylight hours, as previous studies in the USA have shown that spiders do not initiate ballooning at night (Yeargan 1975; Bishop 1990), and our segregation of day and night suction trap catches confirmed that few spiders balloon at night in UK. Thus, we report observations made between 0700–2200 h. The average number of spiders climbing the sticks per observation was calculated for each day. Comparison between the numbers in suction trap samples and the numbers on BI, were performed for the 78 days when both suction traps were in operation, and BI were observed four or more times.

RESULTS

During the study period we collected a total of 8772 spiders in the 1.4 m high suction trap (uncorrected numbers) and 3781 spiders in the 12.2 m suction trap and we observed 1079 spiders in BI during a total of 649 observations. Linyphiidae constituted 96% and 92% of spiders caught in the 1.4 m and 12.2 m suction traps, respectively. The spiders from BI were not identified to species, but a very high proportion were Linyphiidae.

In order to indicate whether the total number of spiders climbing sticks could be used as a measure of ballooning intent, the number of spiders showing tip-toe behavior was compared with the total number climbing. There was a highly significant correlation ($r = 0.98$, df = 76, $P < 0.001$), hence, the total number of spiders climbing was used as response variable. On no occasion were any spiders recorded climbing when wind speed was above 3.5 ms^{-1}.

To see how well BI detected aerial dispersal, the days on which all three methods agreed in detecting occurrence or non-occurrence of dispersal were counted. On 74% of days all three methods agreed, and when only the 1.4 m suction trap and BI were compared there was agreement on 82% of days. The three methods showed a very similar pattern of aerial dispersal, as can be seen in Fig. 1. Most peaks of aerial dispersal (17 of 21) matched in all three methods, but suction traps detected more peaks than did BI, which could be expected as suction traps operate continuously 24 h/day. Not only the pattern but also the magnitude of aerial activity agreed for all three methods. BI showed better correlation with the 1.4 m suction trap ($r = 0.69$, df = 76, $P < 0.001$) than with the 12.2 m suction trap ($r = 0.46$, df = 76, $P < 0.001$). This was probably due to BI and the1.4 m suction trap operating at approximately the same height.

Climbing activity was greatest in the morning, and most ballooning attempts had ended before 1300 h (Fig. 2). In summer, activity appeared to peak earlier than in spring and autumn, probably because the sun rises earlier in summer. In July and August climbing activity was already high when BI was started, hence, activity peaks may have been missed. However, the three methods did not differ more in July and August than the rest of the study period (Fig. 1).

The suction traps were better correlated with each other ($r = 0.90$, df = 76, $P < 0.001$) than with BI. In general the 1.4 m suction trap caught more spiders than the 12.2 m suction trap. On 84 out of 575 days of sampling the 1.4 m suction trap caught spiders when the 12.2 m trap did not, whereas the opposite was true only on 33 days (Fig. 3). This suggests that more spiders balloon near to the ground, hence the 1.4 m suction trap is a better measure of aerial activity than the 12.2 m trap.

There was no systematic difference in the proportion of spiders caught in 12.2 m and 1.4 m suction traps at different times of year (Fig. 4). Hence there is no indication of spiders failing to reach higher elevations during autumn and winter, at least not at this study site during the two years of sampling.

DISCUSSION

Spiders only climbed the sticks when wind speeds were below 3.5 ms^{-1} which lends

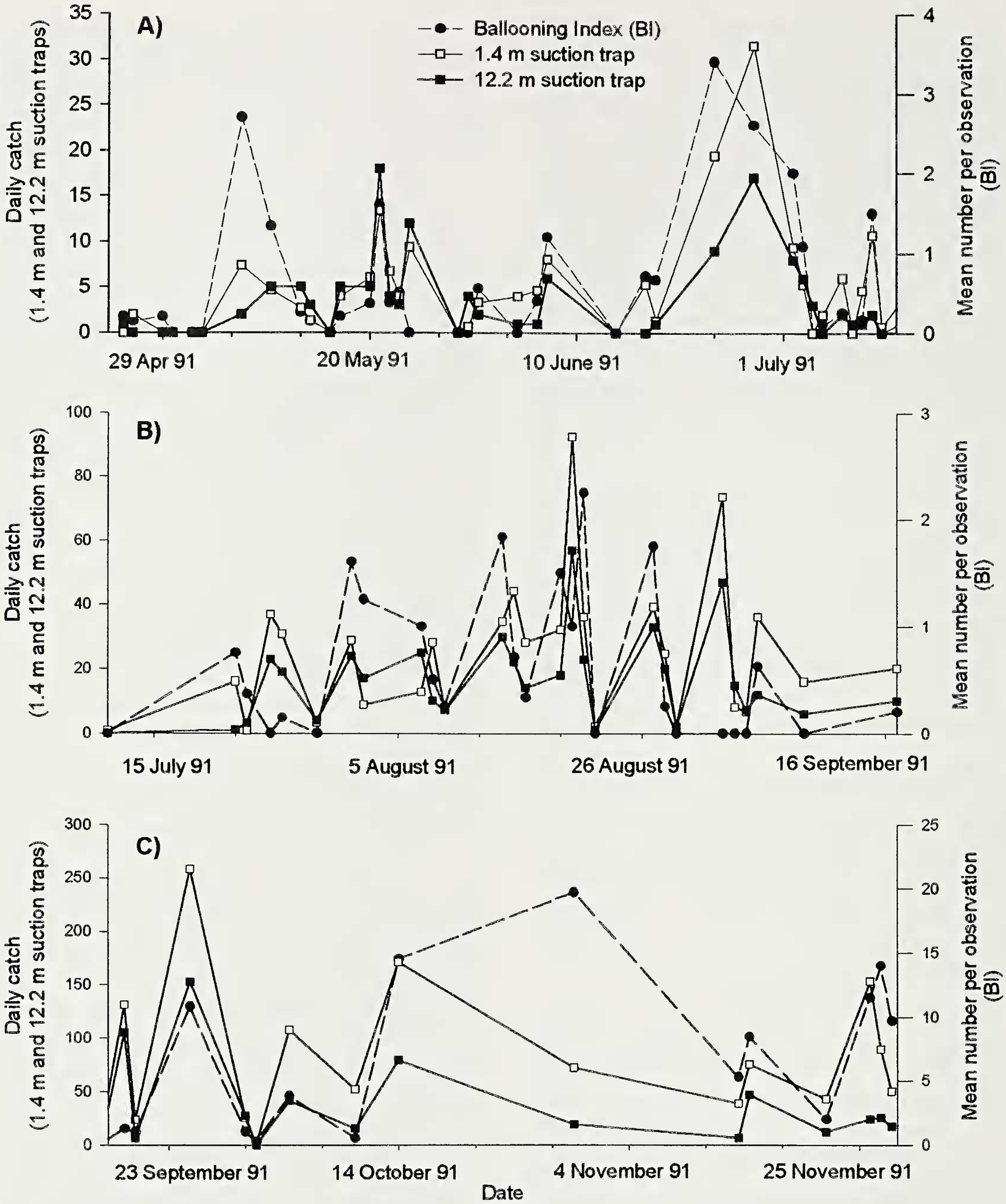

Figure 1.—Ballooning activity measured by BI (monitoring climbing activity of spiders on an array of sticks), 12.2 m suction trap (Rothamsted Insect Survey Trap) and 1.4 m suction trap (46 cm Enclosed Cone Propeller Suction Trap). A) spring and early summer (24 April–11 July 1991). B) late summer (11 July–17 September 1991). C) autumn (17 September–28 November1991).

weight to the contention that BI is a measure of ballooning activity, because otherwise spiders would also have been expected to climb sticks in weather not suitable for ballooning (Weyman 1993).

The match in the results among the three methods was generally good, thus the pre-ballooning activity of spiders on the ground corresponded well with aerial density. Suction traps were slightly more sensitive than BI to ballooning activity, which was expected since the suction traps sampled continuously for 24 h/day, and data from BI were from as little as four observations per day. Where there are discrepancies, many of them can probably be explained by the fact that the suction traps were emptied several hours after sunrise, therefore one day's sam-

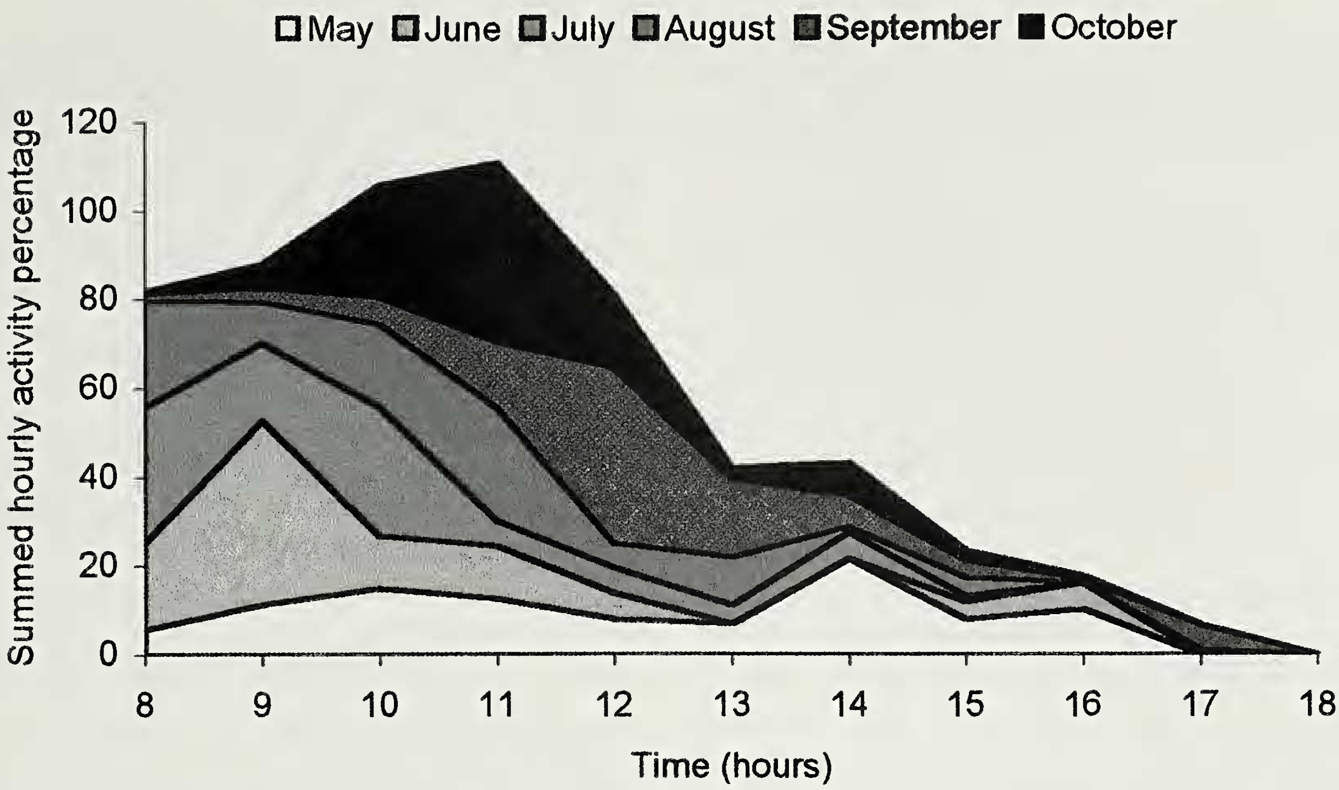

Figure 2.—Observations of spiders climbing sticks (BI) in relation to month and time of day. The hourly activity was calculated separately for each month, and is displayed cumulatively. The hourly activity was calculated as the percentage of spiders climbing at a given hour out of the total numbers of spiders that were observed climbing the sticks that month.

ple could often contain spiders from parts of two days.

Vugts and Van Wingerden (1976) found that ballooning starts 1–4 h after sunrise. This agrees well with our finding that ballooning started earlier in summer than in spring and autumn. Therefore if BI is used, effort should be concentrated in the morning rather than in the afternoon. To have continuous monitoring of ballooning motivation one could use adhesive-coated sticks as Duffey (1956) did. However, adhesive-coated sticks present other problems. Flying insects clog them during the summer months (Duffey 1956), it takes time to sort the spiders from trapped insects, and at low temperatures the glue becomes too stiff to trap the spiders. Studies may also have to

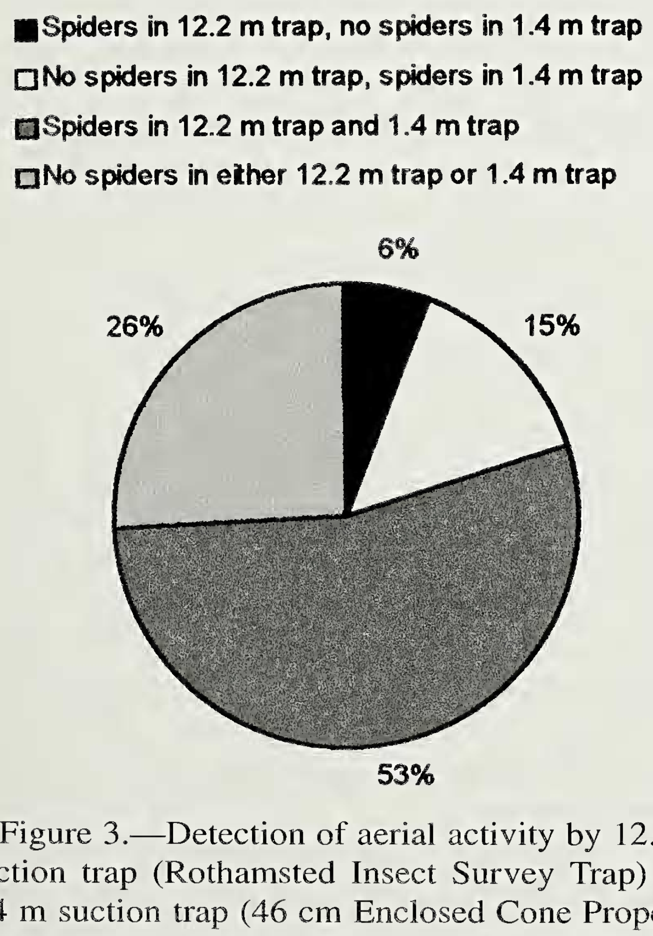

Figure 3.—Detection of aerial activity by 12.2 m suction trap (Rothamsted Insect Survey Trap) and 1.4 m suction trap (46 cm Enclosed Cone Propeller Suction Trap). In total the traps were in operation for 575 days.

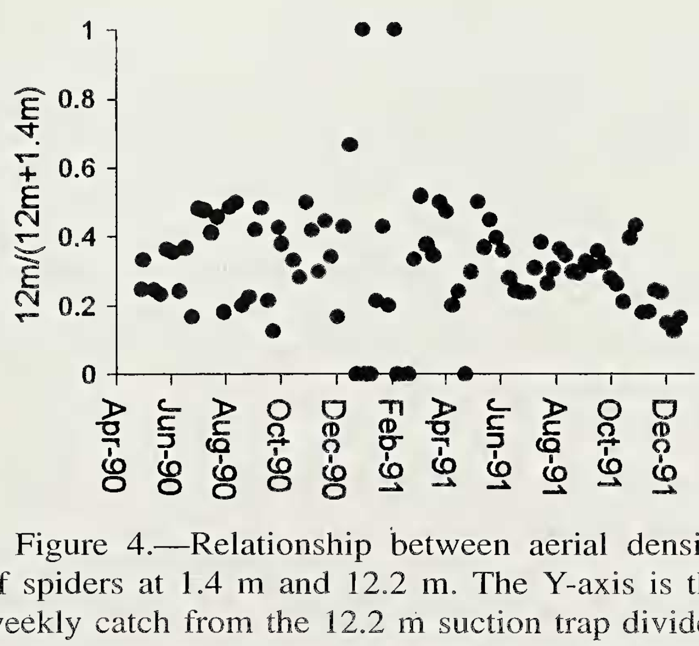

Figure 4.—Relationship between aerial density of spiders at 1.4 m and 12.2 m. The Y-axis is the weekly catch from the 12.2 m suction trap divided by the total weekly catch in both 12.2 and 1.4 m suction traps.

be done to determine how well spiders are trapped by the adhesive, as there seems to be some difference between the sexes (Thomas 1992).

BI may not be appropriate for climbing species that also forage on vegetation, but for Linyphiidae it appears to be a reliable method. We suspect that the method is mainly measuring re-ballooning attempts by grounded aeronauts that landed on the short grass turf and climbed up the nearest vertical structure, as it was not likely that such a small strip of short grass would support a spider population of the size indicated by the number of spiders climbing the sticks. If this is the case, then BI could be used as an index of aerial activity even for the airspace above tall crops, providing that the array of sticks is placed in a cleared area of bare ground or short vegetation (within or at the edge of the tall crop).

In general there was good agreement between different methods for monitoring ballooning activity of spiders. In a previous study (Topping & Sunderland 1995) results from a deposition trap, a 1.4 m suction trap, a rotor trap and sticky traps were also highly correlated. This indicates that spiders take-off, balloon and land within the same short period of time. In the present study more spiders were ballooning close to the ground than at 12.2 m, indicating that most spiders were not lifted very high on air currents. Traditionally, it has implicitly been assumed that spiders balloon by a few long flights (e. g., Greenstone et al. 1987; Greenstone 1991; Sunderland & Topping 1993; Toft 1995). However, it has recently been proposed that spiders in general balloon by many short flights, often only travelling a few meters per flight (Topping et al. 1992; Thomas 1992). Thus, during an aerial dispersal event, a spider will take-off, balloon some distance and land, then repeat this process until it has found a suitable habitat or as long as weather allows ballooning (Tolbert 1977; Heidger & Nentwig 1989). If ballooning is mostly by a few long flights, then BI would measure mainly emigration, and deposition traps would measure mainly immigration. However, if spiders balloon by many short flights, then BI, suction traps, sticky traps and deposition traps will all catch a combination of spiders taking-off and spiders landing, and spiders leaving, entering or just passing through/over the habitat cannot be separated. The data presented here suggest that the majority of aerially dispersing spiders make a number of short-duration flights, as more spiders were consistently caught in the 1.4 m suction trap than in the 12.2 m trap. This was consistent throughout the year, i. e., no seasonal change in the ratio of numbers caught at 1.4 m and 12.2 m, indicating that the seasonal changes in height distribution and distance travelled, suggested by Toft (1995) for Denmark, do not apply in UK. Hence, spiders would also be able to re-colonize fields in winter. However, the distance that a spider can disperse in a day will depend both on the distance of flights and on how long the climatic conditions allow re-ballooning. Our data suggest that spiders balloon fewer hours per day during autumn than spring and summer.

To help researchers to select an appropriate method for their own circumstances we here compare the man-hours and costs needed for BI, suction traps, deposition traps and sticky traps. BI takes 5 min per observation and a minimum of four observations a day, so in total it would take 2h 20 min/week. However, this can be greatly reduced if observations are only carried out at wind speeds below 3.5 m/s. The costs of materials are negligible (below US $5). Suction trap samples take around 15 min to collect and count, in total 1 h 45 min/week. The cost of the 1.4 m Propeller Suction Trap is approx. US $1600 and US $3900 for the 12.2 m Rothamsted Insect Survey Trap. The water traps used by Topping and Sunderland (1995) took on average 1 hour per trap to sort and count, however during summer this may be up to three hours per sample. Topping and Sunderland (1995) used 6 traps, which took 6–12 h/week. The deposition traps used by Topping and Sunderland (1995) were fairly expensive (approx. US $80 per trap), but a simpler and cheaper design could be used. Sticky traps would take approximately the same time to process as water traps with the same sampling effort. However, in summertime they do get clogged quickly and have to be changed at shorter intervals. Materials would cost approximately US $10 per trap per week.

In conclusion, the pre-ballooning activity measured by BI corresponded well with aerial density measured by suction traps (especially when considering the very different mechanism of BI and suction traps, the large difference in sampling effort and variation in timing of observations for BI). Hence, BI appears to be a robust and useful method for measuring aerial dispersal activity of spiders. It uses inexpensive equipment and its total cost will be very low if the array of sticks can be sited close to a laboratory or a frequently-manned field station. If, however, the array is set up in a remote location, then travel and labor costs have also to be taken into account when deciding whether to use BI or a more automatic system (such as a suction trap emptied at weekly intervals).

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